# CHAPTER III

## DATASETS & METHODOLOGY

This study inter-compares skin temperature retrievals from the GOES-8 Imager and Sounder. The retrievals are also compared to land ground truth data and to buoy sea surface temperatures. Finally, for a small case study, GOES-8 and GOES-11 data and retrievals are compared. The comparisons of Imager to Sounder data are computed over three different domains, a CONUS region, a SouthEastern (SE) United States region, and an ocean region. Three different domains were selected so that the retrieval characteristics could be examined over both land and water. The SE domain is a subset of the CONUS domain, and can therefore be expected to provide similar results, but also more detailed analysis of a land region. The SE domain exhibits less ST variability than the whole CONUS domain and also often has less influence by cloud contamination. A map displaying the locations of the three domains is shown in Figure 3.1. The following sections describe the data used and their sources, and the software and computer languages used to analyze the data, and the methods employed to perform the analysis.

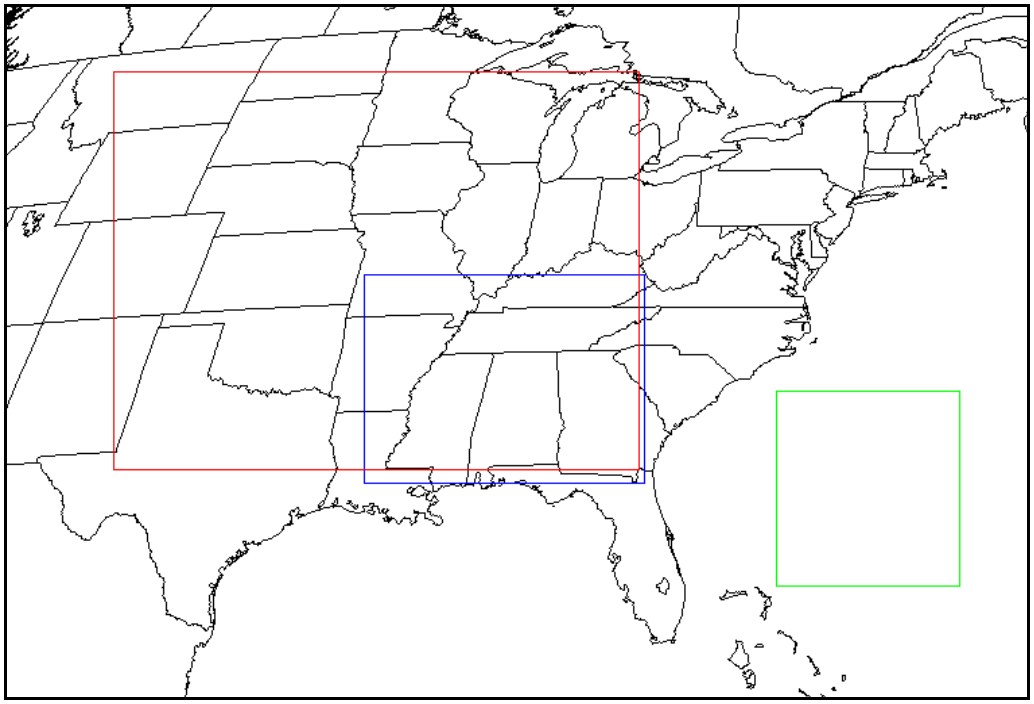

Figure 3.1 Map of the study domains, showing the CONUS domain (red), SE domain (blue) and the ocean domain (green).

### 3.1 GHCC GOES-8 Imager and Sounder Data

All the GOES-8 Imager and Sounder images are ingested in real-time at the GHCC by a satellite ground station. The data is received in GVAR format and then calibrated and navigated using Man computer Interactive Data Access System (McIDAS) (Suomi et al. 1983). The McIDAS software is designed to provide interactive analysis, management and display capabilities of weather satellite data (see the University of Wisconsin – Madison Space Science and Engineering Center's McIDAS web site at http://www.ssec.wisc.edu/software/mcidas.html for more detail). The Imager and Sounder CONUS imagery are archived at Marshall Space Flight Center (MSFC). The current day's imagery is placed in McIDAS image format on Abstract Data Distribution

Environment (ADDE) servers and is easily accessible from within the GHCC. Data from GOES satellites are expensive to obtain from outside sources; therefore, this research relied upon the imagery ingested at the GHCC. Certain hardware and software problems occasionally caused images to be lost or of bad quality, and therefore the dataset for this research is not always complete.

### 3.2 GOES-11 Data

The GOES-11 satellite was launched on May 3, 2000. It was positioned at 104W during the science test, and is currently located between the two operational satellites and will remain so until one fails and will then be moved and take the failed satellite's place. A GOES-11 science test was conducted from June 30, 2000 through August 13, 2000. During this test period almost continuous imaging of the CONUS was performed every five minutes.

Three days of GOES-11 science test data were obtained from Jamie Daniels of NOAA/NESDIS. Imager and Sounder data for July 25-27, 2000 was supplied to the GHCC by NESDIS on DLT tape in McIDAS area file format. The data tape contained 5 minute imagery, some 1 minute imagery, and Sounder images every 30 minutes. Not all times for all days were available; therefore, there are gaps in the hourly comparisons with GOES-8 data.

### 3.3 GHCC GOES Retrievals

The GHCC ST and PW retrievals are derived directly from GOES-8 Imager and Sounder data using the PSW technique. The PSW algorithm requires first-guess profiles of temperature and moisture. The first guess files are produced from real-time mesoscale model weather forecasts using the Penn State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model (MM5) produced at the GHCC and provided by Dr. William Lapenta (GHCC/NASA). The current GHCC MM5 model configuration is 36 km resolution for the CONUS domain, and 12 km resolution for the SE domain. The MM5 model provides forecasts every hour of temperature and relative humidity profiles.

The first guess profiles together with the spectral response curves of the split-window channels are the major inputs into the forward radiative transfer model "Simrad." Simrad calculates transmittance values at 40 different pressure layers throughout the atmosphere twice, once using the moisture values provided by the first-guess data, and once using moisture values set at 80% of the original values. The two profiles are used to determine a perturbation of transmittance due to moisture change, providing all the terms on the right-hand side of Equation (2.5) (see Section 3.3) to calculate the coefficients C and D. Simrad truncates all input profiles with pressure levels greater than 1000 mb to 1000 mb; therefore, errors for regions with higher pressure levels (for example, the sea surface) can be expected. Simrad has been compared to 18 other IR radiative transfer models using a diverse range of atmospheric profiles (Garand et al. 2001) and was found to be one of the poorer performing models. The study found that Simrad's error bias of brightness temperature for longwave IR window channels could be as large as 1 K. However, the radiative transfer model study used some extreme profiles normally not found in the United States that caused some large errors. Under typical atmospheric conditions, Simrad's bias is normally less than 0.5 K. Future improvements to the PSW technique include replacing the older Simrad code with a newer, more robust radiative transfer model.

The profiles of transmittance and moisture provided by Simrad, the brightness temperatures from the GOES satellites, and the first-guess skin temperature are used together to solve for the coefficients C and D, the perturbation of ST, and subsequently the ST values, (Equations (2.7) and (2.8)) using the Fortran program MATRET. The MATRET code partially includes surface emissivity effects on the left-hand side of the perturbation Equation (2.4), but ignores the atmospheric reflectance term. The output of MATRET includes McIDAS format image files and point files of total PW and ST. The image files must be of 8-bit resolution (a limitation of McIDAS), although averaging of pixels can be performed.

The retrieval process occurs once every hour from 11-23 UTC using the 45 minutes past Imager and Sounder images. The Fortran programs are called by a series of scripts within a UNIX operating system on a Silicon Graphics Interface (SGI) machine. There are also several scripts utilizing McIDAS programming commands that analyze the retrievals from the McIDAS image files. Analysis of the data was performed using McIDAS, UNIX scripts, and Fortran programs on the SGI workstation. Further analysis and plots were generated using Interactive Data Language (IDL) on a second SGI workstation, and PV-WAVE and Microsoft Excel on a personal computer.

Statistics were computed during this research on ST retrievals from the GOES-8 Imager and Sounder. For the three domains pictured in Figure 3.1, the mean temperatures and the standard deviations from the mean were computed. Two different computation methods were used. First, in order to analyze the Imager and Sounder data using similar datasets and the same cloud mask, the same number of pixels from both instruments were selected. This was achieved by selecting for each clear Sounder pixel the nearest single collocated Imager pixel (also required to be clear). Second, with the purpose of utilizing all of the available data, statistics for each instrument were computed independently, such that all the clear pixels for each instrument were used. The first and second methods will henceforth be referred to as method 1 and method 2 respectively.

Skin temperature hourly tendencies were also computed. The tendencies were computed by using all pixels that were clear for both of the hours of the tendency. For each pixel the difference between the second and first hour was determined and then the domain tendency was calculated as the average of all the pixel tendencies. The Imager and Sounder tendencies were computed independently.

**3.4 Calculation of Striping Errors within GOES Images**

A method to quantify the striping in GOES Imager scenes is described in Baucom and Weinreb (1996). Their method selects 4 lines x 7 elements uniform regions from GOES-8 Imager calibrated IR scenes. The 14 pixels for each detector are averaged and the striping is defined as the difference between the two detector averages. For this study 10 lines x 18 elements uniform regions were selected from Imager channel 4 and 5 scenes. Because of the pixel overlap in the sampling process, a 10 x 18 pixel Imager region corresponds to a square region of approximately 40 x 40 km at nadir. For the Sounder, 4 lines x 4 elements (40 km by 40 km) pixel groups were selected. A region larger than that used by Baucom and Weinreb (1996) was selected for the Imager so that the Imager region would be close in size to the smallest possible square Sounder region.

The Sounder region requires at least four lines because of the four detectors utilized by the IR channels of the Sounder. For each satellite results were computed for channels 4 and 5 from the Imager, and channels 7 and 8 from the Sounder. Detector numbering throughout the study was selected randomly, since the detector numbers of individual lines of a region were unknown.

The Imager striping is defined as the difference between the average brightness temperatures of the two detectors viewing the same region but adjacent lines. Sounder striping is not defined by Baucom and Weinreb (1996) and, because of the different number of detectors, there is not a Sounder method equivalent to the Imager method. The following method to determine the Sounder striping was selected to provide values to best describe the striping magnitude. The Sounder striping in this research is defined as the average of the differences between brightness temperatures of adjacent detectors viewing adjacent lines. The largest difference between adjacent detectors is also given.

Regions uniform with respect to IR window brightness temperatures were selected manually and only those with standard deviations less than 1 K were included in the analysis. The standard deviation limit ensures that the chosen sectors have near constant brightness temperatures (i.e., little or no natural scene variation), with variation due to noise only. For each satellite sensor four regions were selected at three different times, giving a total of twelve regions for each channel. For each image, the root mean square (RMS) of the four striping errors was computed. Over the three images, the RMS error was averaged. This method is adapted from the one described by Wack and Candell (1996).

### 3.5 Ground Truth Data

Ground truth data of skin temperature is very limited. Air temperature measurements are widely observed, but the GOES satellite measures the radiation being emitted from the surface, and thus the temperature derived is the skin temperature, not the air temperature. There can often be large differences between the skin temperature and the air temperature. Because of these large differences, air temperatures cannot be used as truth-values when validating skin temperatures derived from satellite data.

The Atmospheric Radiation Measurement (ARM) program uses many different platforms to gather data and operates several research sites called Cloud And Radiation Testbeds (CARTs). The Southern Great Plains (SGP) site of the ARM program has a down-looking Infrared Thermometer (IRT) that measures the radiating temperature of the ground surface. The IRT is positioned 25 m above the ground in a wheat field and provides measurements of the equivalent blackbody brightness temperature within the 10-12 μm atmospheric window, assuming an emissivity value of 1.0. The location of the ARM site is shown in Figure 3.2 and a photo of the central facility of the SGP site is shown in Figure 3.3. The data can be obtained from the ARM archive in network Common Data Form (netCDF) format and is accessible through the Internet (http://www.archive.arm.gov/cgi-bin/arm-archive). Interactive Data Language was employed to read the ARM netCDF files and to produce plots of ST at the ARM site. Ground skin temperature measurements are provided by the IRT every 20 seconds and are plotted at this temporal interval. When time specific comparisons to the GOES data were required, the ARM data was averaged over a four minute interval centered on the satellite retrieval time. The ARM data is used in this study as ground truth data.

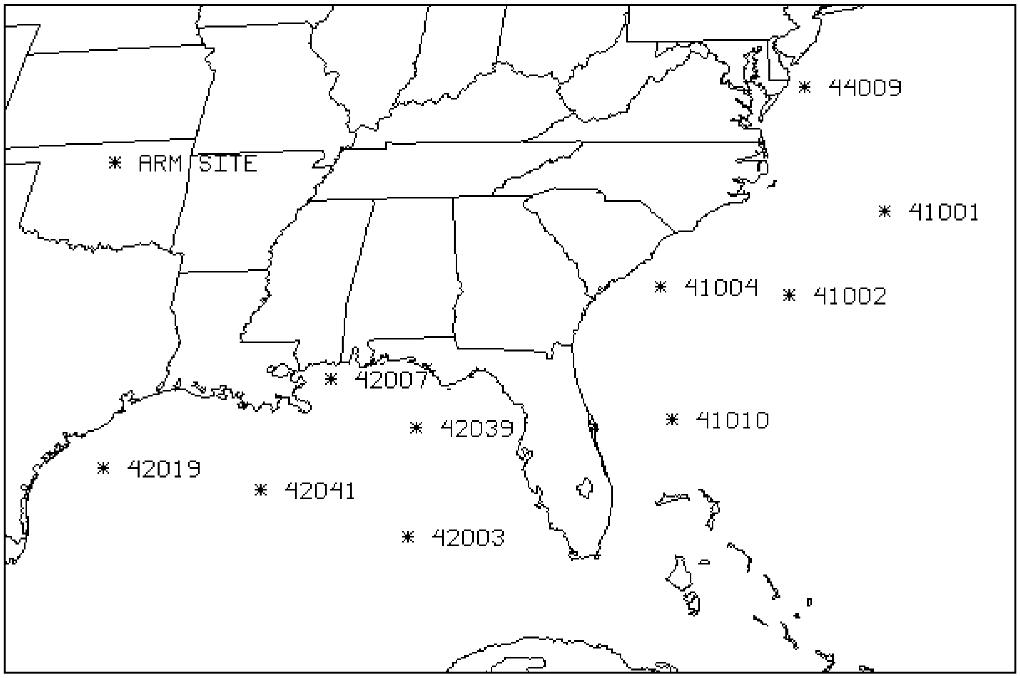


Figure 3.2 Locations of the ARM SPG site and the ten selected buoys.

Figure 3.3 ARM Southern Great Plains central facility site (available online at http://www.arm.gov/general/photolibrary/photos.html).

An important factor to consider when comparing ground truth data to satellite data is the spatial resolution of these measurements. The skin temperature measured by the IRT is for a region only a few meters across. The satellite spatial resolution is on the order of kilometers. The satellite sensor obtains information from a much larger region; large enough that temperature should be expected to vary because of different land use across the region. Figure 3.3 is a photo of the ARM SGP central facility site and surface type variations are obvious. Comparisons between the GOES retrievals and the ARM data, therefore, can be expected to show some differences because of the variation in spatial resolution.

The viewing angle can also be expected to cause differences in temperature measurements. The IRT is looking straight down upon the observed location and the observed signal is mostly from the ground surface not the surface cover. The GOES-8 satellite is viewing the ARM IRT location (36.607 N 97.489 W) 36,000 km above the equator at $75^{o}$W. The satellite views the surface as well as the sides of the surface cover and therefore the observed signal is a mixture of the surface signal and the surface cover signal. Viewing the same region from different angles may produce differences in temperature observations, particularly in mountainous regions (Lipton and Ward 1996), and over areas where terrain varies.

### 3.6 Buoy Sea Surface Temperature Measurements

Sea surface temperature (SST) measurements are more widely available than LST measurements. Moored buoys provide SST values every hour. Although the PSW algorithm was designed for retrieving land ST, SST values are also obtained and can therefore be used for comparisons to help validate the retrievals. Ten buoy locations were selected for this study; Figure 3.2 shows the locations of these ten moored-buoy stations. The data is available through the internet from the National Data Buoy Center (NDBC) in text file format (http://www.ndbc.noaa.gov/index.shtml). The buoy SST measurements for the chosen buoys are taken either at 1.0 m or 0.6 m below the sea level.

As with the ground truth comparisons, there are considerations to be taken when comparing buoy SSTs with satellite retrieved SSTs. Again, the measurement area and viewing angles are significantly different. In addition, the depth at which the SST values are taken is not the same as the depth from which the satellite measures. The IR channels of the GOES satellites receive longwave radiation emitted from the sea, from a depth of approximately 10 μm, therefore measuring the skin temperature of the ocean (Donlon et al. 1998; Wick et al. 1999). There is a temperature gradient between the ocean surface and the depth at which the buoys measure, and this temperature gradient can vary throughout the day as a result of changes in solar heating (Wick et al. 1999). The temperature at 0.6 or 1.0 m depth may be significantly cooler than the surface temperature. Solar variations have more effect at the surface than at 1.0 m below the surface and therefore skin temperatures and can be expected to vary throughout the day more than temperatures 1.0 m below the surface. Satellite retrievals of ST can be expected to be warmer and exhibit more diurnal variation than the buoy SSTs.